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STRESS REVIEWS

I. THERMAL STRESS - COLD

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FORWORD

As one task related to the understanding of environmental variables accounting for behavior variance, our staff has undertaken extensive study of a variety of literatures related under the general topic of stress. A series of working papers was prepared, summarizing these reviews of the literature. These have been edited and will be reproduced for the use of colleagues who may find the compilations of value. The Stress Reviews completed to date cover extremes of the physical environment, involving cold, heat, radiation, and atmospheric extremes.

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THERMAL STRESS: I. COLD[1]

SECTION 1. INTRODUCTION

Heat and cold are well-known sources of stress in military situations involving extreme temperatures and have been the subject of extensive laboratory studies and a number of field investigations in several scientific disciplines. The current military activity in the tropics, and the long-standing military operations in the severe conditions of the arctic and antarctic programs, high altitude and space flights, and long range undersea operations have greatly increased the need for knowledge in the areas of thermal stress, acclimatization, thermal injury, and protective measures. Because of the sheer complexity of the problem of thermal stress, due to the varied influence of numerous variables producing joint effects on behavior, the quantity of experimental research in this field can be regarded as slight when compared with the questions that still remain unanswered. The area of the influence of extreme environmental conditions on human behavior is still in its infancy.

The interaction of heat and cold with humidity, air movement, clothing insulation, physical exercise and other factors in affecting the psychophysiological behavior of the human organism has been relatively well studied. Much less is known, however, on the facilitating or inhibiting effects on resistance to thermal stress of other relevant variables, such as air ions, radiation, drugs, diet, isolation,

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[1]This report is an extended version of an earlier paper by Nurhan Findikyan and S B Sells entitled Cold Stress; Parameters, Effects, Mitigation (Arctic Aeromedical Laboratory, Aerospace Medical Division, Air Force Systems Command, Fort Wainwright, Alaska) AAL-TR-65-5, Sept. 1965.

fear, darkness, motivation, personality traits, group structure, task orientation, and task load. Consequently, thermal extremes cannot be considered independent sources of stress exerting uniform effects on the human organism independent of other interacting organismic and environmental states. The study of thermal stress, as the study of all other known variables, is a multifaceted problem and needs to be viewed as such if adequate generalization to practical and realistic situations is to be made possible.

The appropriate conceptualization of the problem requires not only recognition and specification of the relevant variables on the stimulus side, but also careful specification of the response (criterion) variables. In experimental situations rectal temperature, shivering, vasoconstriction, and blood pressure have often been taken as indicators of thermal stress. In a military real-life situation the successful accomplishment of a task or mission under thermal stress, without irreversible damage to the human organism, would be of more direct concern than these associated physiological reactions, although these latter may be useful in understanding performance effects in terms of their demonstrable influence on the accomplishment of the task.

Thus, the question to be asked in the evaluation of performance effects of thermal stress is not what degree of shivering and vasoconstriction occurs or how far the rectal temperature drops under a specified stressful environmental circumstance, but rather the extent to which a given task or mission can be successfully accomplished in the frame of reference involving particular categories of individuals and the observed changes in body temperature, vasoconstriction, shivering, and other reactions. Definitive answers to this last question, with reference to various environmental situations, would be of practical value in aiding the planning and execution of arctic, antarctic and tropical civilian and military operations. Yet answers of this nature are few in the literature, and those that do appear are largely based on anecdotal reports.

A word of clarification is in order at this point. In seeking molar answers to questions of extreme environmental stress, molecular investigations into bodily changes in physiological functions are not irrelevant. Indeed, molar answers to practical questions depend heavily on molecular facts. With-

out detailed information on specific physiological processes under stress no satisfactory, adequate, and thorough molar answer is possible. However, such information by itself is insufficient and the very exigency of understanding behavior mechanisms in complex, real-life situations clearly points to the fact that research on a molar scale under the closest possible simulation of realistic environmental conditions and real-life missions and tasks is badly needed.

Although extremes of heat and cold are conceived to be two ends of the same continuum, and psychophysiological reactions to heat and cold have been categorized under the rubric of "thermal stress," the biological and psychological responses to extremes of heat and cold, in most instances, appear to be different. These differences are further accentuated by the fact that extreme heat and cold are characteristics of different environmental conditions. As a result, the discussions of heat and cold in the review are separate.

The emphasis on the difference between heat and cold stress and their respective environments in which they occur should not be a deterrent, however, to the quest for higher order similarities between the two states. In fact, heat and cold stress do show certain common properties in their interactions related to health, motivation, physical fitness, and the fact that tolerance of both heat stress and cold stress increases with adaptation and decreases when other stresses operate simultaneously with them.

Further research in the area of thermal stress might lead to the formulation of more subtle, more refined, and more meaningful similarities between heat and cold stress to supplement the crude resemblances listed herein.

The review undertaken in the following pages is centered on cold stress. A separate report has been prepared, extending the coverage of thermal stress to heat. Although an effort has been made in the current review to summarize information obtained through field observations in real-life situations as well as through molecular laboratory research on cold stress, the paucity of field studies in the literature is reflected in the report.

SECTION 2. MECHANISMS OF BODY TEMPERATURE CONTROL UNDER COLD EXPOSURE

Most of the biological functions of the human body make adjustments in order to maintain a homeostatic balance. Under light, moderate, or extreme variations in environmental temperature the thermoregulative mechanisms of the body make critical physiological adjustments to maintain a stable internal body temperature. Rectal temperature is generally accepted as being representative of internal body temperature, and as a rough measure of the temperature of such vital internal organs as the lungs, heart, brain, and abdomen. Its normal range varies from 36.2°C (96.8°F) to 37.6°C (98.6°F). Variations within this range, due to age, sex, emotional state, dietary status, physical activity, health, climate, diurnal and individual cycles, are common occurrences (Adams, 1960). Rectal temperature remains fairly constant, varying only 2° or 3° F (1 or 2°C) while the environmental temperature might fluctuate 75°F (42°C) and the heat production of the body may increase or decrease severalfold from normal (Bruce, 1960).

In cold environments the thermoregulatory centers of the body function to maintain stability of the normal body temperature by compensating for heat losses through heat gains. The particular methods of maintaining the normal body temperature within a species or between species depend on the availability and flexibility of heat exchange mechanisms (Adams, 1960).

In certain animals, such as frogs, regulatory mechanisms for preserving a constant body temperature are either absent or poorly developed so that in low environmental temperatures the body temperature of these animals approaches the temperature of the environment. Hibernation appears to be a form of survival mechanism in species lacking thermoregulatory devices of adjustment.

Under exposure to cold, human compensatory responses start to occur at temperatures below 20°C (68°F) (clothed and at rest) or at 28°C (82.4°F) (naked) (Macfarlane, 1963) to maintain body temperature within a very narrow range of 2-3°F. The

blood loses most of its heat to the environment when circulating in the network of arterioles, venules and capillaries found just beneath the skin. Under conditions of cold stress these blood passages near the periphery are constricted and blood flow is diverted away from the surface to conserve body heat. This is known as vasoconstriction. As skin temperature is reduced, reflex cutaneous vasoconstriction occurs in toes, feet, hands, nose, and ears. Venous pressure rises and venous volume decreases. These physiological adjustments in turn reduce blood flow near the skin. With reduction of skin temperature the heat gradient between the skin and the environment is diminished, thus reducing heat exchange between the colder environment and the warmer body. Blood returning from the periphery starts to flow back via deeper venous routes. These alternate routes allow cool venous blood to pass adjacent to warm arterial blood channeled toward the periphery. Returning venous blood is thus prewarmed before entering the heart. Concurrently arterial blood is cooled, thus minimizing heat loss upon reaching the periphery (Adams, 1960, Bruce, 1960).

Convective heat loss is also reduced by the erection of hairs and roughening of the skin. This response tends to minimize air movement next to the skin (Bruce, 1960).

Bruce (1960) indicated that vasoconstriction reached a maximum and conductance a minimum for both nude and clothed subjects when the average skin temperature is 8°F ([illegible]-5°C) below rectal temperature.

Adams (1960) cited work by Hardy and DuBois in support of the conclusion that conduction is not substantially reduced at temperatures below 28°C (82°F). Thus, supplementary mechanisms of adjustment are required.

As environmental temperature decreases, the body resorts to mechanisms of thermogenesis. One form of heat production is gross shivering which tends to compensate for heat loss with which the adjustments cited above have not been able to cope. Shivering seems to occur with rectal temperatures below [illegible]°F ([illegible]°C), although its onset is apparently retarded when the rate of fall of deep body temperature is slow (Bruce, 1960). Muscular activity initiated by physical exercise

can also inhibit or delay involuntary shivering.

To supplement further and aid the mechanisms of thermal balance mentioned thus far, muscle and liver metabolisms, and thyroid and adrenal hormones are summoned into action. An increase in output and turnover of thyroxin and adrenal cortical hormones is observed. It is interesting to note that the response pattern of output of thyroxin and adrenal cortical hormones observed under extreme cold also occurs in other stress situations (Macfarlane, 1963).

Below rectal temperatures of 27°C-30°C (80°-86°F) the pattern of heat conservation through vasoconstriction, shivering, and increased endocrine output ceases to be effective and all central and peripheral cold mechanisms fail (Adams, 1960).

Bruce (1960) suggests that deep body temperature can be maintained near 98°F (37°C), for limited periods, in environments ranging from -40°F to 135°F (-40° to 57°C), through the proper choice of clothing and efficient thermoregulation. He cites 25°C (77°F) as the lowest limit of rectal temperature at which life can be maintained for a limited time. These time limits, however, he fails to specify. In real-life situations human time-tolerances of cold would be exceedingly hard to specify since ambient or rectal temperatures are not the only independent variables and the effects of activity, caloric intake, acclimatization, clothing, wind, humidity, and the like need to be taken into consideration.

Several physiological reactions to cold in addition to the ones mentioned above have been cited by Tromp (1963, p. 243). These consist of larger urine volume, lower respiratory metabolism, decreased oxygen saturation of the blood, and the higher pH of urine.[2]

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[2]A detailed account of biophysiological responses to cold and an anatomic and functional description of the thermoregulation center is given by Tromp (1963).

Although environmental temperature is discussed as a single variable, the interactive or additive effects of other stressors present in the environment, in addition to cold, as mentioned above, must not be overlooked. It is generally accepted that the presence of additional stressors has the effect of lowering the biological and psychological stress-resistance capacity of the organism. Two important physical environmental factors that operate in conjunction with cold to increase the effects of cold stress are humidity and air movement.

HUMIDITY

It is well-known that there is no substantial difference in the nonevaporative heat loss of the skin whether humidity is high or low. It is also widely accepted, from verbal reports and personal experience, that an increase in humidity almost invariably is accompanied by feelings of discomfort during either warm or cold weather. Yet, a few experiments have presented evidence contrary to this everyday "knowledge" and common expectation. In an experiment by Burton, Synder and Leach (1955), as reported by Tromp, nine unclothed subjects were exposed lying down for 100 minutes to temperatures of 48° and 58°F (9 and 14°C) with 30 per cent and 80 per cent relative humidity, respectively. Skin temperatures remained practically the same under these widely different degrees of humidity, but on exposure to cold, rectal temperatures rose more when humidity was low, suggesting a greater physiological response to vasoconstriction. The incidence and intensity of shivering and the sensation of cold were greater when humidity was low, despite the fact that skin temperatures were the same. The surprising result of this investigation was that the subjects reported a greater sensation of cold with low humidity, whereas the opposite would usually be expected. Several other experimenters have obtained different results. However, Tromp (1963, p. 224) explained the discrepant reports of comfort with different levels of humidity by stating that humidity as such cannot be perceived by the human body and that only differences in humidity at a given temperature are perceived.

Despite the conflicting results of different experiments, it is fenerally accepted that greater discomfort is experienced during cold humid weather.

The capacity of the skin to absorb moisture, which increases thermal conductivity of the skin near the cold receptors, can be one of the various factors accounting for the increased sensation of discomfort (Tromp, 1963, p. 225). There is no evidence, however, that different thermoregulatory mechanisms are marshalled into action when the air is humid, nor that thermogenesis follows a different pattern. The same reactions that take place in dry and cold weather, probably take place in humid and cold weather. Whether the temperature threshold at which the various thermoregulatory mechanisms start their emergency functions is lowered or heightened in cold and humid air is a point that needs clarification.

AIR MOVEMENT

It is common knowledge that air movement has a cooling effect on the body, which increases with the speed of movement. Air movement increases heat loss from the body as it disturbs the fairly constant layer of warmed air that surrounds the body in still air. Tromp (1963, p. 231) has suggested that there is an adequate rate of air movement that creates an invigorating environment and that variable rather than monotonous air movement is more bracing. His suggestions apply primarily to air movements in a room or building, but can probably be extended to breezes in temperate climes. Arctic winds on the other hand, are uniformly detrimental to survival under extreme cold and inhibit to a great extent the accomplishment of an outdoor mission. Tromp (1963, p. 226) reported that a skin temperature of 32.5°C (90°F) at an ambient temperature of 15°C (59°F) drops 11.30°C (20°F) at windspeeds of 282 cm/sec. (about 111 in./sec.)

Arctic winds coupled with snow flurries do not only lower the temperature of the body, thus taxing the physiological functioning of the organism, but also make the accomplishment of an outdoor task extremely difficult, if not impossible. Snow driven into the eyes obstructs vision to a substantial degree and goggles are of no great use since they freeze up almost immediately. This situation helps to emphasize the point that physiological adaptation to cold in a cold chamber, while relevant for the controlled study of the phenomenon in molecular perspective, is only an intermediate objective in the study of psychophysiological effects of realistic cold environments on behavior.

OTHER FACTORS

In contrast to the relatively extensive information on the interaction of cold with humidity and air movement in reducing the physiological resistance of an organism to meteorological stress, comparatively little is known about the effects of air ions, polarized light, electrical fields, and several other climatological and meteorological variables on the human body. How these variables would interact with cold in modifying the physiological mechanisms of the human organism and thus influence the performance of a task or accomplishment of a mission is hard to conjecture. Scientific progress in psychobiometeorology has been slow. Yet, several studies of recent vintage may soon provide enlightening new information on the effects of meteorological variables on behavior (Tromp, 1963; Muecher and Ungeheuer, 1961; Moos, 1964).

SECTION 3. PHYSIOLOGICAL INJURY AND DYSFUNCTION SUFFERED IN EXTREME COLD

The parts of the body most susceptible to cold-injury are the extremities, which present the largest exposed surface, for heat loss, from the underlying core. Macfarlane (1963) listed three types of cold injury.

A. Chilblains. Chilblains are a relatively mild form of tissue damage. Poor circulation, as a result of cold, results in damage to the tissue of the extremities. Local itching and swelling characterize this form of injury.

B. Wet cold syndromes. The main exemplars of these injuries are the well-known trenchfoot and immersion foot. They result from exposures below 12°C (53°F) for several days. The moisture from cold and sweat contribute to the pathogenesis of these disorders. Feet and legs become cold, pale, numb and cease to sweat. After initial vasoconstriction, vasodilation takes place and the feet become red and swollen. Nerve injury is frequent. Hypalgesia and anesthesia persist for weeks after the feet have been warmed. Blood vessels are damaged and plasma and red cells leak into tissue spaces.

C. Frostbite. These injuries result from prolonged and severe vasoconstriction at temperatures below 0°C (32°F). In mild cases, tissue is not necessarily frozen. In more severe cases, ice penetrates the tissue causing necrosis, and very often gangrene sets in if circulation has been severely reduced. On warming of the injured extremities, vasodilation and swelling occur. Considerable pain and damage to liver, kidneys and adrenals are sometimes noted (Lewis, 1955; Macfarlane, 1963).

Environmental factors, such as winds coupled with cold, and organismic variables, such as poor circulation in

the extremities, increase the danger of cold injury. Lewis (1955) classified cold injuries into categories as to their degree of severity. These are characterized by (a) loss of superficial dermal layer, (b) loss of full thickness of skin and superficial subcutaneous tissue, (c) loss of deep subcutaneous tissue and distal parts, and (d) loss of major tissue, including bone. Results of experiments by Lewis indicated that nerve and muscle tissue were more susceptible to cold injury than skin, connective tissue, tendons and bone.

Drury (1964) reported three stages by which ice invades the tissue:

A. Superficial freezing. This occurs at high subzero temperatures. A thin blanket of ice spreads over and underneath the thin layer of tissue, advancing in all directions.

B. Intercellular freezing. In this stage, ice from the superficial layers starts spreading between the cells. In invading this intercellular space the advancing ice uses tissue elements and collagenous fibers as pathways.

C. Intracellular freezing. Ice invades the cells and blood cells freeze suddenly. Ciliary activity is irreversibly affected. Upon warming, the erythrocytes burst and blood vessels assume an irregularly beaded bulbous appearance.

The treatment of bodily injuries resulting from severe cold is a problem that has been given considerable attention. The literature indicates that severe injuries received under extreme cold are usually irreversible. This is attributable to the fact that frostbite is rarely detected by the individual at its incipience. By the time that it reaches suprathreshold levels, extensive damage to tissue and blood vessels has already taken place. The condition is often further aggravated by the concomitant effects of delay in transporting the injured person from an isolated region back to a hospital with adequate medical facilities. Gangrene and damage requiring amputation of fingers and toes are quite common.

Specific therapeutic procedures are usually of little avail when irreversible tissue damage has already taken place. Meryman (1953) reported that rapid thawing of frozen tissue may inflict further damage. Lewis and Hoak (1956) corroborated Meryman's finding that delay of rapid rewarming for 30 minutes reduces the extent of gangrene. The results of these experiments suggest that damage to tissue occurs not only when tissues freeze, but also in the thawing period as well.

Fuhrman and Fuhrman (1957), however, mentioned the more rapid onset of hyperemia and edema after rapid as opposed to slow thawing as one of the main disadvantages of rapid thawing, and concluded that delayed warming is never superior to rapid thawing.

Theis et al. (1951) found that the clinical use of heparin reduces the extent of gangrene and the duration of hospitalization. Douglas (1960) reported negative results for ultrasound therapy in frostbite.

Several authors have expressed the considerable doubt and disagreement as to the best method of treatment of cold injury that exists in medical circles. As Theis et al. (1951) pointed out, the prevalent objective of cold injury treatment is the prevention of further damage rather than restoration of damaged parts and functions, since in most cases of cold injury these have been irreversibly affected.

Lewis (1955) emphasized the increased likelihood of frostbite due to malnutrition and fatigue, thus drawing attention to the multifaceted nature of cold stress.

SECTION 4. DETERIORATION OF TASK PERFORMANCE UNDER COLD STRESS

Cold stress not only affects the physiological mechanisms of the body, producing such reactions as shivering and vasoconstriction, but also produces decrements in task performance. Numbness of the fingers produced by cold stress leads to deterioration particularly of performance on tasks requiring fine manual dexterity. As a consequence, duties requiring manipulation of knobs, switches, push-buttons, keys, screws, nuts and bolts become well-nigh impossible to accomplish.

EFFECT OF COLD ON SENSORY PROCESSES

According to Williams and Kitching (1942) no change occurred in the area of visual field, in two subjects who were exposed to a temperature of -50°F (-46°C) for one hour and to lower temperatures for greater durations. Another subject dressed in a flying suit with auxiliary heat to the hands and feet manifested no change in the area of the visual field despite a rectal temperature drop of 1°C (1.8°F). In all cases, the area of the visual field was determined by use of a perimeter subtending one degree of visual arc with a white spot serving as the test stimulus.

The effects of arctic conditions on vision are of considerable practical interest. Compared to findings concerned with decrease of excitability in temperate zones, a regular increase of excitability of the visual and auditory organs of man has been observed in the arctic (Funtikov, 1964). Revesman, Hollis, and Mattson (1953) concluded that there is apparently some change in vision in the arctic. The studies reviewed indicated there is greater eyestrain, more errors in distance judgment, and more detrimental effect on pilots under arctic conditions. Although the effects on audition are less well explored, there is evidence that arctic hoods restrict hearing.

Cold reduces tactual sensitivity that is necessary

for the completion of many jobs involving such actions as turning knobs, flicking switches, and pushing buttons.

Provins (1958) suggested that the reduction in tactile discrimination and other kinesthetic sensitivity that occurs in cold conditions might be especially important in driving under icy conditions, at night, or with reduced visibility.

Bartlett and Gronow (1952) found increased tactile discrimination in the first 30 minutes of exposure to a temperature of -10°C (14°F). This improvement might have been the result of a learning factor, but, in any case, it indicated that for short periods of exposure, improvement in tactile discrimination was not precluded by exposure to cold conditions of this magnitude.

Mackworth (1952) reported a significant effect of both air temperature and wind-speed on tactile discrimination. Subjects were exposed for three minutes to either cold air (-25.1°C to -30°C) (-13°F to -22°F) or very cold air (-30.1° C to -35°C) (-22°F to -31°F) in wind conditions described as calm (0-6 mph) or breeze (6-10 mph). The greatest numbness assessed by the millimeter increase in gap size that could be detected was found under the condition of very cold air with air speed of 6-10 mph. A change in wind speed was found to be as effective as a change in air temperature.

Russell (1957) found an impairment in tactile sensitivity when temperatures dropped below 30°C (86°F) and in kinesthetic sensitivity when temperatures dropped below 20° C (68°F). Testing temperatures in the range of -18° to -23°C (-0.4°F to -9.4°F) for exposure periods of approximately 21 minutes, Mills (1956) found that tactile discrimination was reduced when skin temperature was lowered. Spontaneous rewarming, after exposure of about 15 minutes, produced a recovery in tactile discrimination as skin temperature rose. If spontaneous rewarming did not occur, frostbite usually ensued.

Provins and Morton (1960) also reported phasic differences in tactile discrimination that corresponded to phases of the "hunting reaction." They had subjects immerse

the index finger in each of six water bath temperatures ranging from 2° to 30°C (35.6°F-86°F) for a period of 20 minutes. It was found that 2-edge discrimination showed little impairment at temperatures of 6°C (42.8°F) or greater, when the finger was in thermal equilibrium with the water. At 4°C (39.2°F) however, marked impairment was noted, and at 2°C (35.6°F), a complete numbness occurred. Provins and Clark (1960) also pointed out the relationship between finger temperature and tactile discrimination and suggested 6°C (42.8°F) as the minimum finger temperature for no impairment of sensitivity.

The relationship between temperature and vibratory sensitivity has been found to be similar to that of temperature and pressure sensitivity suggesting similarity if not identity in the controlling mechanisms of the two (Weitz, 1941).

The radiant heat pain threshold has been found to increase under conditions of low ambient temperature (Teichner and Kobrick, 1955).

MUSCLE STRENGTH

Provins (1958) reported the reduction in hand-strength under conditions of cold stress which is particularly relevant to cyclists. Horvath and Freedman (1947) found that exposure to extreme cold for periods of three hours can greatly reduce hand grip strength. The grip pressure of 70 men exposed to temperatures of -10° to -14°F (-23° to -26°C) showed a 28 per cent drop. Craik and MacPherson (1943) had two subjects immerse their hands in water at 7°C (44.6°F) for 15 minutes. Hand grip strength was reduced 21 per cent and the strength of opposing the fingers to the thumb was reduced 44 per cent. The lesser effect on hand grip strength was attributed to the greater involvement of forearm muscles which were protected by clothing and presumably not cooled as much as the small muscles of the hand which are involved in the opposition of the fingers and thumb. The authors concluded that local cooling of the limb and not general body cooling is the primary factor to be considered in loss of muscle strength in the cold.

Provins and Clarke (1960) found that loss in muscle strength as a result of exposure to cold is a function of the

amount of local cooling of the muscles below a temperature of 81°F (27°C). Below this temperature, there will be a reduction in the period of time that a submaximal contraction can be maintained.

MANUAL DEXTERITY

Reduced sensitivity is generally, though not always, associated with a reduction in manual dexterity. Bartlett and Gronow (1952) found that, while tactile sensitivity was not impaired by exposure to temperatures of -10°C (14°F), the normal improvement in manual dexterity that occurs at room temperature was prevented from taking place at these temperatures.

Rohles (1953) examined performance on a typing test as a measure of both manual dexterity and serial discrimination as a function of ambient temperature. Tests were given after a 30 minute adaptation period to temperatures of 70° (21°C) (control), 60°, 50°, 40°, and 30°F (16°, 10°, 5°, -1°C). Gloves were worn during the adaptation period. The group at 60°F (16°C) had the fastest typing time and the groups became progressively slower at the lower temperatures. The mean number of errors increased as temperatures became lower.

Horvath and Freedman (1947) gave 22 men a series of tests including the Johnson Code Test and the Gear test. Although the former is generally considered a measure of mental performance, it also served as an indicator of manual dexterity as it is a paper and pencil test. Performance on both these tests was much poorer at -20°F (-29°C) than at 72°F (22°C). The decrement on the Johnson Code Test was attributed to a loss in manual dexterity rather than to any interference at the cortical level.

Manual dexterity has been found to be related to hand-skin temperature. Clark (1961) investigated the effects of hand-skin temperatures of 55° and 60°F (13° and 16°C) on a knot-typing task in 12 enlisted men after the criterion temperature was reached, and after 20, 40, and 60 minutes exposure at criterion temperatures. Performance at hand-

skin temperatures of $60^{\circ}F$ ($16^{\circ}C$) showed no evidence of impairment. At $55^{\circ}F$ ($13^{\circ}C$) hand-skin temperature, performance was severely impaired, the performance decrement being an increasing exponential function of duration of exposure, becoming asymptotic at approximately 40 minutes. Dusek (1957) while finding no significant relationship between finger-skin temperature and finger dexterity, found that lowered ambient temperatures resulted in a greater reduction in fine finger dexterity than in gross hand dexterity and in greater variability and a decreased level of performance of manual tasks. In this study, subjects were exposed to temperature conditions of 75° ($24^{\circ}C$) (control), 55°, 45°, and $35^{\circ}F$ (13°, 7°, and $2^{\circ}C$) for periods of 90 minutes and during exposure were administered the Minnesota Rate of Manipulation, O'Conner Finger Dexterity, and Purdue Pegboard Tests.

Springbett (1951) found that hand temperature was related to impairment of performance on the Minnesota Manual Dexterity Test, the Bolts Test, and the Bren Test. Although he suggested that duration of exposure should be included in the estimation of limiting hand-skin temperature, hand temperature of approximately $26^{\circ}C$ ($78.8^{\circ}F$) could be considered the limit for efficient performance. This temperature limit is considerably higher than that mentioned by Clark (1961) who found no evidence of impairment at $60^{\circ}F$ ($16^{\circ}C$), but did at $55^{\circ}F$ ($13^{\circ}C$) on a knot-tying task.

Several studies have been designed to determine whether local cooling or total body cooling is the critical factor in reduced manual dexterity in the cold. Springbett (1951) tested manual dexterity under conditions of warm body-warm hands, warm body-cold hands, cold body-cold hands, and cold body-warm hands. It was found that, regardless of body temperature, subjects with cold hands showed a significant decrement in performance, while those with warm hands showed no such decrement.

Gaydos (1958) had 12 enlisted men perform knot-tying and block-stringing tasks under two conditions. In one condition, the hand was warmed to a temperature of $80^{\circ}F$ ($27^{\circ}C$) while the body was exposed to an ambient temperature of $45^{\circ}F$ ($7^{\circ}C$); in the other condition, the entire body was

exposed to the ambient temperature of 45°F (7°C). The results showed a decrement in manual performance when hand-skin temperature dropped to 50°-55°F (10°-13°C), which did not occur when hand-skin temperature was maintained at 80°F (27°C) or higher, despite body surface cooling to 78°F (26°C) in both cases.

A similar study was conducted by Gaydos and Dusek (1958) who had 16 enlisted men perform knot-tying and block-stringing tasks in one situation, where the ambient temperature was 15°F (-9°C), or in another, where hands were exposed to a temperature of 5°F (-15°C), while the rest of the body was exposed to a surrounding temperature of 70°-80°F (21°-27°C). Tests were made immediately after the subjects began the session, when finger-skin temperature dropped to 65°F (18°C), and again when it dropped to 50°F (10°C). No difference in performance was found when the total body was exposed to temperatures of 15°F (-9°C) or when just hands were exposed to 5°F (-15°C) while the body remained warm. Performance on both tasks was found to decline as finger-skin temperature decreased.

A series of experiments by LeBlanc (1956) indicated the importance of keeping the forearm, as well as the hand, warm in order to maintain manual dexterity in the cold. LeBlanc used two tests, one involving maximal flexion of the joint (90°) and one involving only about a 15°flexion. Dexterity was tested under conditions where only the arm, only the hand, or only the finger, was cooled. The decrement in manual dexterity that occurred when only the arm was cooled indicated that factors other than increased viscosity of synovial fluid were operating. The impairment was attributed to some arm muscle impairment. The author concluded that impairment would be possible even when the body was cold and the hands were warm. The stiffness in joints that occurs as the result of increased synovial fluid viscosity was considered to be a prime factor in loss of finger dexterity in the cold: the greater the flexion required by the task, the greater the impairment.

Coffey (1955) in an investigation of manual dexterity and joint stiffness found that manual dexterity declined progressively as joint surface temperature dropped below 6°C

(42.8°F) There was a concomitant though sharper decline in joint flexibility.

Provins and Clarke (1960) concluded that local cooling of the hand or arm produces a significant decrement in manual dexterity regardless of the general body temperature. Cooling of the hand or finger probably has its detrimental effect through interference with joint movement. Forearm cooling has more deleterious effects, probably as a result of increased muscle viscosity of the long flexors and extensors located in the fingers.

Clark and Cohen (1960) investigated the relationship between manual performance and the rate of change in hand-skin temperature. Twenty enlisted men performed a knot-tying task while their hands were cooled at two rates and then rewarmed. Only the hands and forearms of the subjects were cooled, while body temperature remained at the normal level. The experimental data revealed that slow cooling produced a greater performance decrement in terms of increased performance time than did fast cooling. The rate of rewarming was a direct function of the rate of cooling. The performance decrement produced by fast warming was no longer evident after rewarming although the decrement produced by slow cooling persisted even after rewarming. In contrast to this Teichner (1957) found that performance time on a one-handed turning task of the Minnesota Rate of Manipulation Test was not affected by either digital cooling rate or by digital temperature. The author suggested that impairment in the cold might be related to an inability to maintain attention on the task than to any direct physiological factor.

Clark and Cohen (1960) examined manual performance in the cold as it was influenced by training conditions. Thirty nude subjects were given 3-weeks of training on a standard manual task with either cold hands or warm hands. One group performed each day with cold hands (45°F (7°C) hand-skin temperature). Another group performed with warm hands (90°F (32°C) hand-skin temperature) on odd-numbered days and with cold hands (45°F hand-skin temperature) on even-numbered days. A third group performed the first ten days with warm hands and the remaining five days with cold hands. It

was found that one day of training under cold conditions was sufficient to reduce the decrement in performance that generally occured although thermal experience beyond this had no additional beneficial effects. The subjects apparently learned during the course of training not only to perform the task, but to perform with cold or warm hands specifically. Thus the thermal conditions became an integral part of the stimulus complex.

The extremities can be rather effectively insulated by gloves and arctic mittens, but those that have been available have been so bulky that they tend to hinder the performance of tasks requiring fine manual dexterity. In this case, personal protective equipment merely exchanges one source of performance decrement for another (MCCleary, 1953). Karstens (1963) also indicated that when mittens and gloves have to be removed periodically in aircraft maintentence work requiring finger dexterity, the result is a substantial loss of effective working time. Blair and Gottschalk (1947) similarly found performance decrement for Signal Corps operators wearing arctic uniforms in environments of -13° to -40°F (-25° to -40°C).

Decrement in performance in extreme environments can also be attributed to substantial energy expenditures incurred in coping with the environment. Rogers, Setliff and Klopping (1964) reported that a solitary survivor in a subarctic environment can be expected to expend from 5000 to 6000 Kcal during the first 24 hours in which he undertakes survival procedures. This caloric cost is independent of environmental temperatures as low as -30°C (-22°F). The drastic caloric deficit incurred through energy expenditures of this nature cannot be met without disastrous exhaustion unless the individual is "thoroughly fit." Performance decrement, malaise, and discomfort in such a taxing situation can be attributed to the caloric loss as well as to "isotonic dehydration and its consequent hypovolemia and hemoconcentration."

Measures for counteracting performance decrement and deterioration in cold environments are many, although none of them is completely satisfactory. Factors instrumental in increasing tolerance of cold stress are reviewed later in this report.

SENSORY MOTOR TASKS

Teichner (1958) found that low ambient temperatures, at low windspeed, had no significant effect on reaction speed (the reciprocal of reaction time); at least down to -35°F (-37°C) and possibly down to -50°F (-46°C) although at windspeeds greater than 10 mph, low ambient temperatures resulted in significant decrease in reaction speed.

Williams and Kitching (1942) tested both simple and multiple reaction times at 0°F (-18°C) (4 hour exposure) and at -50°F (-46°C) (1-1.5 hour exposure period). The data were analyzed according to best 10, worst 10, and average of the 50 trials. Simple reaction time at 0°F (-18°C) showed little change in the best 10 trials although there was some deterioration at the worst 10. Normal temperatures usually restored the performance level. At -50°F (-46°C), for two subjects there was no change in simple reaction time, while in the other five there was a sharp decline, evident especially in the worst 10 times. In the multiple reaction time experiment, there were no significant changes at either 0°F (-18°C) or -50°F (-46°C). There was a possibility, however, that the deterioration was masked by an end effect. Peacock (1956) found no evidence of cold stress affecting serial reaction time.

Horvath and Freedman (1947) found that performance at -20°F (-29°C) on a simple visual discrimination task revealed no evidence that this temperature affected speed, precision, or reaction time. Provins and Clarke (1960) concluded that reaction time performance may be somewhat impaired, particularly under conditions where local cooling of the hand occurs and something more than light pressure is required to make the response. This implies that the increase in reaction time is more a result of an interference with the response modality than with the sensory modality. Fulton, as reported in Forlano (1950), suggested that with extended exposure to cold that is sufficient to produce a drop in rectal temperature, both motor performance and cerebral activity are slowed so that there is a decline in efficiency. Provins and Clarke (1960) found that while a drop in body temperature can increase reaction time, some deterioration in performance can occur without a temperature drop, apparently as a result of distraction caused by the discomfort of the cold.

Debons and Chiles (1957) investigated the effects of cold on psychophysical weight judgment at temperatures of 70° (21°C) (control), 0° (-18°C), and -25°F (-32°C). The variances for both subjects were significantly greater at 0°F (-18°C) and for one subject at -25°F (-32°C) than those at 70°F (21°C). This was considered to be indicative of reduced sensitivity for both subjects at 0°F (-18°C) and for one subject at -25°F (-32°C). The conclusion was that weight judgments are adversely affected at low temperatures when metal weights are used.

A number of studies have investigated the effects of cold stress upon tracking performance. Teichner and Wehrkamp (1954), investigating the range of temperatures from 55°-100°F (13°-38°C) in 15° intervals, noted a decline in performance both above and below 70°F (21°C). The data suggested a more marked decline at the lower than at the higher temperatures, indicating that cold stress might be more detrimental to tracking performance than heat stress. Teichner and Kobrick (1955) found that performance on the pursuit rotor showed an immediate and marked decline at 55°F (13°C) as compared to 75°F (24°C), which showed some improvement but never regained the level attained under optimal conditions. Visual-motor performance was impaired, apparently as a result of reducing the final performance level rather than interfering with the rate or limit of learning.

Russell (1957) investigated both free-movement and pressure control tracking tasks and found the range of effective temperatures for them differed. Pressure tracking showed impairment at temperatures below 68°F (20°C), while movement tracking was not affected adversely until temperatures dropped to 50°F (10°C). Newton (1957) studied the possible difference in cold sensitivity of pressure and movement tracking. Measures were taken at a control temperature of 24°C (75°F) and at temperatures of 0°, -5°, -10°, -15°, and -20°C (32°, 23°, 14°, 5°, -4°F). An analysis of the data revealed that an interaction between temperature conditions and task conditions did occur, but only when individual differences among subjects were considered. There were no main effects due to differences in ambient temperature, although these could have been masked by the interaction effects.

The effects of cold temperatures on a manual coordination task, in which a light was followed with a writing pen, the movements of which were controlled by two rotary handles, were studied by Williams and Kitching (1942). The subjects performed for 15 minutes at temperatures of -3° to 8°F (-19° to -13°C) during the test period or at 30°-50°F (-1°-10°C) in the control period. The subjects were allowed to warm their hands during rest intervals of 15 minutes. No significant deterioration was noted in the performance levels under these conditions. It is possible that such factors as absence of other stressors, (i.e. fatigue), the simple task, and the opportunity to warm the hands prevented the effects of cold to manifest themselves.

Payne (1959) investigated the possible influence of body heat loss on tracking proficiency and the ameliorative effects of glycine. There were three temperature conditions: 70°, 55°, or 40°F (21°, 13°, 4°C); and three drug conditions: 20 gm. glycine, 40 gm. glycine, or 2 gm. saccharin in solution. After 50 minutes of work the 40°F (4°C) groups displayed the sharpest decline in performance level, while the 55°F (13°C) groups displayed the greatest efficiency. The glycine treatment produced no reduction of impairment.

MENTAL TASK PERFORMANCE

Less emphasis has been placed upon the investigation of mental performance under low ambient temperatures than on physical performance under the same conditions. Torrance (unpublished manuscript) reported the effect of cold on a verbal recall task. A group of men, briefed in the open air at 8°F (-13°C) was allowed to rewarm before the verbal recall task. The group allowed to rewarm recalled about twice as much as the group not allowed to rewarm.

Horvath and Freedman (1947) administered the Johnson Code Test to 22 men living in a cold chamber for 8 to 14 days. Although the Code Test was a measure of mental performance, it inevitably measured manual dexterity, as it is a paper and pencil instrument. Performance was found to be much poorer at -20°F (-29°C) than at a temperature of 72°F (22°C). The decrement at lower temperatures was attributed by the investigators to be reduced manual dexterity rather than to deterioration of mental performance.

SECTION 5. DETERIORATION OF MORALE AND AFFECTIVE DISORDERS UNDER COLD STRESS

Isolated cases of cold neurosis have been cited in the literature of cold stress (Macfarlane, 1963). Incidents of deterioration of morale, anxiety, increased irritability, depression, sleep loss, and personal untidiness in extremely cold environments (military and scientific arctic missions) have also been reported (Reidy, 1960).

Burns (1945) studied 325 psychiatric casualties among military personnel in the Aleution Islands. Of the 325 cases 80 per cent were found to have exhibited various psychiatric symptoms before entering the service. Therefore, in most of these cases the hardships and stresses of the environment were assumed to have precipitated the psychoneuroses in individuals predisposed to neuropsychiatric disorders. Although complaints about the climate, the monotony and the value of the work being done, isolation from families and civilization, and poor prospect for rotation were rife, Burns did not consider any of the factors to be crucial stressors. He concluded that men with well integrated personalities withstood the tour of duty in the arctic very well. Individuals with such adverse early background influences as broken homes, death of parents, strict discipline, and the like were found more susceptible to psychiatric disorders. He recommended lectures on mental hygiene, on the importance of the mission, and on understanding and accepting attitude on the part of line officers toward the men, as preventive and therapeutic procedures to lessen the incidence of neuropsychiatric problems on arctic posts.

On the whole, despite common belief, it is significant that informed scientific opinion is skeptical concerning any direct relation of neuropsychiatric behavioral manifestations to the effects of the cold environment. In most cases individuals exhibiting symptoms reported were well-protected from the cold. The uncontrolled effects of fear, remoteness, isolation, confinement, interpersonal

friction, and lack of effective leadership have been judged to have contributed more to deterioration of personal habits, behavior, and morale than the cold environment per se. In most cases the individuals exhibiting deteriorating tendencies could be said to have adjusted poorly to their respective situations and would probably have exhibited the same symptoms under other stresses in those situations. Such difficulties may involve the physiological mechanisms of thermal adjustment, but it is generally recognized that poor psychological adaptation is not necessarily indicative of poor physiological adaptation to the cold.

SECTION 6. SUPPORTIVE AND PROTECTIVE MEASURES IN RELATION TO COLD STRESS

Several means of protecting the human organism and enhancing task performance in cold environments have been studied intensively. These range from physiological acclimatization, through clothing and diet, to selection of "fit" individuals, and group dynamics. The following sections review some measures that have been found useful in preparing the human organism for cold stress as well as means and devices that have a salubrious and positive effect on task performance and mission accomplishment.

ACCLIMATIZATION

As mentioned earlier, the maintenance of high body temperatures while functioning in low ambient temperatures is crucial to survival and comfort in cold environments. The adjustment of physiological functions to cold environment, with resulting increased capacity to withstand low temperatures, is known as acclimatization. The process of acclimatization utilizes fine and complex mechanisms, the cellular basis of which is not yet well understood (Macfarlane, 1963). Acclimatization is usually achieved within one week, but two or three are generally necessary to reach a steady state. At the outset of acclimatization, the physiological compensatory responses reviewed in the preceding pages are manifest. Shivering, peripheral vasoconstriction, increased venous pressure, diuresis, accelerated thyroid and adrenal cortical hormone production, "hunting" oscillation of finger blood flow (See discussion below of tests for thermoregulative efficiency), and increased oxygen consumption depict the pattern of physiological reaction to cold stress.

In the unacclimatized individual, despite these responses to maintain body heat, conservation of normal body temperature is not as effective as in the fully acclimatized individual. The acclimatized organism wastes considerably less heat than the unacclimatized (Macfarlane, 1963). Acclimatization is indicated as a cardiovascular,

endocrine, and renal emergency activation become less and less manifest. The initial increased output of adrenal and thyroid hormones, elevated blood pressure and diuresis, shivering, increased oxygen consumption, and vasoconstruction start diminishing. Macfarlane pointed out that this pattern of sudden increase and gradual decrease in emergency reactions, specifically endocrine output, is the same as that which the organism manifests in response to a variety of stressors. As the initial overswing upon exposure to cold stress gradually subsides the individual is said to be acclimatized.

Davis (1961a, 1961b, 1961c, 1962), in a series of meticulous and painstaking studies, investigated the process and effects of acclimatization. He demonstrated that acclimatization was more efficient, faster, and retained longer when subjects were exposed to low temperatures, unclothed and unprotected, in cold chambers. Because this method involved scheduled exposure and utilized cold chambers, rather than "natural" exposure in the daily course of living in cold climate, Davis referred to it as "artificial" acclimatization. While natural acclimatization to cold was found to be lost in the summer months, artificial acclimatization was retained through the summer into the next winter. Studies at Fort Knox and in Alaska showed that individuals, appropriately clothed for their daily living, failed to acclimatize fully, although they did so to the same extent, irrespective of the range of daily environmental temperatures. Thus, just living in cold environment (Alaska) was not sufficient to induce full acclimatization even when it occurred under natural living conditions. It seems, therefore, that artificial acclimatization to cold has definite advantages over natural acclimatization.

Several indices of acclimatization have been used separately or together by different investigators. These have ranged from skin and rectal temperature, peripheral circulation, and shivering, to subjective feelings of comfort. Oxygen conservation, heat production, and changes in enzyme and endocrine systems have also been utilized as indices of acclimatization. Davis (1961a) found the most desirable index of acclimatization to be shivering, which

decreased significantly in subjects artificially acclimatized in cold chambers. Rectal temperature showed a significant decrement as a result of acclimatization in one study, yet in other investigations by Davis this index failed to show consistent changes.

Davis reported no meaningful changes in skin temperature of any area of the body as a result of acclimatization procedures. Milan et al. (1961), on the other hand, investigating the physiological responses of naturally acclimatized individuals in the antarctic, observed an increase in skin and foot temperatures over the year, but found no difference in rectal and finger temperatures. Manifest decrease in shivering from fall to winter and spring was evident.

Seasonal variation in acclimatization to cold is an important variable to be considered in both natural and artificial cold acclimatization. In naturally acclimatized subjects seasonal cold acclimatization, as indicated by Davis, reaches its maximum around March and is at its minimum in September. Davis (1961a) found a significant decrease in heat production in nude subjects exposed to cold in the summer, but no change in heat production in subjects artificially acclimatized in the winter. These findings indicate that the winter group started its artificial acclimatization with a lower level of heat production than did the summer group. In both groups, however, heat production remained above basal level throughout the duration of the experiments. The decrease and eventual cessation of shivering, and the high heat production despite the cessation of shivering are interpreted by Davis as evidence for mechanisms of nonshivering heat production.

Studies of cold endurance and task performance of acclimatized subjects have been given less attention than they deserve. Eagan (1962), measuring resistance to finger cooling, observed that mountaineers, who had undergone extensive cold exposure for 45 days on Mt. McKinley, and Eskimos living in Northern Alaska were able to withstand the exposure better than the control subjects. Some of the mountaineers who had not suffered

cold injury maintained more economical finger temperatures than the Eskimos. Miller and Irving (1962) reported that Eskimos have higher minimal and terminal finger temperatures than whites; in addition, "unaccustomed" white men experienced marked discomfort to hand cooling as compared with Eskimos and whites accustomed to cold.

Nelms and Soper (1962) found higher finger temperatures both during vasoconstriction and vasodilation in experienced fish filleters than in controls, when their hands were immersed in cold water. Some control subjects fainted, others experienced considerable pain, whereas the filleters were unaffected. Tromp (1963, p. 241) reported an experiment by Glaser and Whittow (1957) in which the pain and rise in blood pressure induced by hand immersion in icy water diminished and were eventually lost after repeated immersions, It appears that people exposed to strong fluctuations in temperature develop an efficient skin temperature control mechanism and adapt readily to cold. Davis (1961a) observed that subjects acclimatized in the cold chamber were able to fall asleep under testing conditions.

All these studies indicate that cold tolerance at the extremities is increased by acclimatization. It is reasonable to state that acclimatized individuals will not experience as much distress under cold as unacclimatized persons and will be able to perform tasks more satisfactorily.

The occurrence of cross-adaptation, including increased tolerance of cold as a result of acclimatization to heat and vice versa, has been mentioned by Trumbull (1964). The basis for and existence of such a mechanism have been brought into question, however, by the work of Davis (1961a), Macfarlane (1963), and others. According to these investigators there seems to be no evidence that heat exposure affects cold acclimatization either favorably or adversely, or that cold exposure increases tolerance to heat stress. In a related study, Barnett (1961) reported that body heating prior to cold exposure is ineffective in extending tolerance to extreme cold.

Tromp (1963, p. 231) indicated that temperatures found uncomfortably warm in the winter are bearable in the summer because of acclimatization to higher temperature in the summer. Conversely, temperatures experienced as cold in the summer are found tolerable in the winter. If anything, such phenomena suggest the opposite of cross-adaptation. The diminution and loss of cold acclimatization over the summer appear to be related, not to the presence of heat, but rather to the absence of cold (Davis, 1961a).

On the basis of all the evidence available it thus appears most likely that the physiological processes of heat and cold acclimatization are independent, that they do not influence one another, yet that they can coexist within the same organism. These physiological processes are also independent of, but interact with psychological processes of accustomization, habituation, and adjustment to places, climates, diets, tasks, social situations, surrounds, and routines. Davis (1961a) emphasized that although manifest physiological changes occur in acclimatization, it would be presumptuous to overlook the roles of psychological habituation and accustomization in the general process of acclimatization.

To recapitulate the practical and applied aspects, artificial acclimatization appears to be an effective way of increasing the cold tolerance of individuals and of helping them to perform more effectively under cold stress.

DIET

Cold stress and acclimatization have been shown to affect, among other things, the endocrine system, enzymes, and metabolism of the body. Torrance (unpublished manuscript) reported a greater tendency to eat fats in colder climates and found that pemmican was more acceptable as a comestible in severe weather conditions. Milan and Rodahl (1961) reported an increased avidity for fat in personnel at an antarctic base.

Rodahl, Horvath et al. (1961) studied the effects of four different diets on physical performance capacity at

temperatures of 22°C and 8°C (71°F and 46°F). At an ambient temperature of 22°C (71°F) no significant differences were found among the four diets. At ambient temperatures of 8°C (46°F) marked deterioration on the treadmill test occurred in subjects living on a diet deficient in calories and proteins. Tromp (1963, p. 242) reported that Vitamin C increases resistance to cold stress and facilitates adaptation by increasing the activity of the adrenal glands.

Kreider (1961) found that composition of diet had no effect on rectal, skin, and toe temperatures at ambient temperatures of 30°F (-1°C). Milan and Rodahl (1961) observed that the percentage of calories, proteins, and fat furnished to antarctic personnel in Little America was not different from that of U. S. troops stationed elsewhere. These investigators attributed part of the avidity exhibited by antarctic personnel to the function that eating might serve in alleviating the tedium of long isolation. The increased caloric intake observed in cold and isolated climes might be a resultant of both physiological and psychological needs.

Rogers, Setliff, and Klopping (1964), in investigating the calorie cost in simulated subarctic situations, found the calorie expenditure to be principally determined by the physical task undertaken rather than by the environmental temperature, when the temperature was above -30°C (-22°F).

In general, this review of the literature indicates that the evidence concerning the value of special diets as a means of increasing cold tolerance is at best equivocal. The importance of proper calorie and water intake, however, cannot be gainsaid even if the use of diets of special composition is of doubtful value.

CLOTHING AND SHELTER

Insulation is a very important measure in counteracting cold stress. Where adequately heated buildings can be constructed, protection can be satisfactorily achieved and

cold stress presents no immediate problem to individuals working and living indoors. Denley (1957) found that even a pneumatic shelter raft can be a satisfactory shelter for emergencies and for short temporary missions in the Arctic. The problems associated with confined living arrangements, however, are major, although largely psychological. As stated before boredom, isolation, and confinement increase the irritability of personnel. Deterioration of morale is noticed. Means of alleviating these tensions are discussed below.

The standard clothing designed for arctic personnel has been well investigated. The types of cloth favored for protective arctic garments are those that have the property of maintaining still air in the interstices and that prevent air from moving within or passing through (Renbourn, 1963). Mayer (1960) found that insulated underwear of 100 per cent nylon with polyester provided the person with adequate comfort im temperatures of -35°F (-37°C) without wearing an arctic parka. The nylon underwear was worn with waffle-weave underwear, MA-1 jacket with hood, pile cap, two pairs of ski socks, one pair of cushion sole socks, CWU/lp coveralls, and mittens. Skrettingland et al. (1961) evaluated the boots worn with cold environments and found the chippewa boot adequate for ambient temperatures of -12°C (10°F). Veghte (1964) found the parka hood adequate without face mask in temperatures of -62°C (-79°F) for 40 to 50 minutes. The coldest skin temperature was 7°C (44°F) and no pain was experienced by subjects.

Despite the adequacy of arctic clothing, the maintenance of temperature in the extremities above critical levels is still a problem. Martorano (1961), in evaluating divers' suits for maintenance of body temperature, observed that the rate and degree of cooling of the extremities were directly related to the thickness of insulation over these areas. Unfortunately, as mentioned above, Skrettingland (1961) and others have reported that tasks requiring finger dexterity are impossible to accomplish with the hands encased in arctic mittens and no satisfactory solution has been found to the problem of performing a fine manual dexterity task in extreme cold while keeping the hands

warm at the same time. As Veghte (1961) has shown, adequate insulation of the body does not ameliorate cold tolerance in the extremities. Veghte's work did demonstrate , however, that with the extremities protected, the rest of the body, with the exception of the ears, could tolerate temperature as low as -18°C (-4°F) for 83 minutes when thermistor underwear was worn.

The maintenance of adequate skin temperature at the extremities is thus a problem that requires further investigation. Karstens (1963) remarked that vasoconstriction and loss of dexterity occur regardless of the amount of mittens and gloves worn. For aircraft maintenance crews working in cold environments, Karstens found periodic rewarming of the extremities and the body in a shelter to be a tolerable, if not satisfactory, remedy. Mobile shelters placed over parts of aircraft have also been found to provide reasonably adequate support in protecting maintenance crews from the cold.

In conclusion, it can be remarked that when the task is not hazardous and demanding and the individual is well insulated, the limiting factor in cold tolerance appears to be the temperature of the extremities. If a satisfactory means of protecting them could be found, performance at extremely low temperatures could be greatly extended.

SECTION 7. INDIVIDUAL DIFFERENCES AND TOLERANCE OF COLD

Individuals differ in the extent to which they experience comfort and distress in the same environmental circumstances. In the same ambient temperature some complain of warmth, while others fret about cold. Some of these differences in experience can be accounted for by adaptation, acclimatization, and habituation. However, a substantial portion of this variance might eventually be accounted for by efficiency and plasticity in physiological mechanisms of adaptation, physical fitness, personality and motivational differences, and other physical and social stimuli in the environment alleviating or aggravating individual feelings and complaints about cold.

DIFFERENCES IN PHYSIOLOGICAL THERMOREGULATION

Considerable differences have been found in thermoregulation in relation to age (Tromp, 1963, p. 229). In infants thermoregulatory mechanisms are not fully developed, and body temperature is closely related to fluctuations in ambient environmental temperature. Thermoregulatory control is attained within two years (Adams, 1960). Buchanan and Hill (1947), as reported by Adams, found a positive relationship between ability to regulate body temperature and the development of myelinization in the hypothalamus. In the old, likewise, thermoregulation becomes poorer. Their circulation is feeble, and their adaptive capacity to change in ambient temperature becomes inadequate (Tromp, 1963, p. 229). Most normal adults have efficient thermoregulatory mechanisms, and until now selection of arctic and antarctic personnel by testing for thermoregulatory efficiency has not been deemed important. Tromp (1963, pp. 252-255) listed the following tests of thermoregulatory efficiency of the human body:

a. <u>Hunting reaction of Lewis</u>. Normally, the temperature of a finger immersed in ice water

drops to 0°C (32°F) at first. A few minutes later, however, the temperature of the finger starts periodic fluctuation between 0°C (32°F) and 5-6°C (41-43°F). Deviation from this pattern of rises and falls can be accepted as an index of a less than normally effective thermoregulatory mechanism. It is most important to determine the normal pattern of the Hunting reaction (and for the other tests listed below) for all age groups in different climatological areas to set up norms for this test.

b. Bedford's air-cooling test. The rise and fall of the temperature of the forehead are measured when an electric fan is activated. Deviations from the normal pattern are observed.

c. Water-bath test. The subject reclines in a chamber with an ambient temperature of 20°C (68°F) and a relative humidity of 50 per cent. The skin temperature of the body is recorded at several places, such as forehead, cheek, and finger. Upon stabilization of the skin temperature a reflex vasodilation of the arterioles is induced by immersing the feet in a warm bath of 45°C (113°F). The time between immersing the feet and the first change in finger temperature, as well as the rate at which the finger temperature increases and the final temperature is reached, is recorded. After the feet have been taken out of the bath, similar observations are made. Tromp recommends that the same procedure should be followed with water at 10°C (50°F), 5°C (41°F), and 0°C (32°F).

d. Blood pressure test. Upon immersion of the hand in cold water the rise of blood pressure is recorded by means of a sphygmotonograph. The rate of increase in pressure and the pattern of the recovery curve are different for individuals with poor thermoregulative mechanisms.

e. Blood flow test. Five cubic centimeters of the third finger of the right hand are enclosed in the cup of a plethysmograph,and the changes in the pattern of blood flow after immersion in water are studied. Persons having poor temperature control mechanisms are expected to deviate from normals.

f. Habituation test. When the tests cited above are repeated daily,the reaction to cold diminishes gradually and may even disappear. Even after an interval of a few days little or no response is observed. Upon renewing the test, persons with a poor ability to adapt and acclimatize to cold show a different pattern of habituation.

g. Diuresis test. In people with normal thermoregulative mechanisms a sudden drop in environmental temperature is usually accompanied by diuresis, an increase in 17-ketesteriod secretion and pH, and a decrease in chlorine secretion. According to Tromp, a deviation in the diuresis curve is indicative of a disturbed thermoregulative process. Several other aspects of the situation should be well investigated and controlled when using the diuresis test. The fluid intake of the person should be recorded prior to the test. This observation should start four weeks before the test. As diuresis is affected by the adrenal cortex, it is desirable to take an adreno-cortical efficiency test.

Despite the variety of methods to test thermoregulative efficiency, none of these has been standardized,and population norms have not been obtained. In addition, frequently observed deviations from the normal have not been adequately described. The need for extensive investigation in this area is manifest.

In an attempt to predict performance under cold stress from physiological measures of skin temperature, McCleary (1953) divided subjects into two groups on the

basis of digital skin temperature under ambient temperatures of 0°, -10°, -20° and -40°F (-18°, -23°, -29°, and -40°C) in a cold chamber. The high skin temperature group completed the assigned manual dexterity task more rapidly than the low skin temperature group. This result led McCleary to suggest that skin temperature might be a proper predictor of performance in the cold. A "sensitivity index" derived by calculating the ratio of the digital skin temperature when the subject reported "cold," to the time that it took to reach this temperature after the onset of exposure, was found to be a fairly satisfactory discriminator of time taken to complete the dexterity task in the cold chamber. The replication of this study with a larger sample, in different climatic zones, with several predictors (e.g. shivering, skin temperature in various parts of the body) and additional performance criteria (e.g. manual dexterity task, verbal learning and recall, problem solving, reaction time) would be a worthwhile undertaking.

PHYSICAL FITNESS

Data on the ability of the "physically fit" man to withstand cold better than the unfit individual are meager despite the general acceptance of the concept. One of the apparent problems in this area is the definition and quantification of measures of physical fitness.

The available literature indicates that a physically fit person performing well in temperate climes will not necessarily perform as well in arctic and subarctic weather. The point of view suggested is that the particular kind of physical fitness required to combat cold stress is that which is acquired through acclimatization, conditioning and training. A person in good health is not necessarily physically fit to withstand the rigors of arctic weather unless he is adapted to it. Eagan (1962) found no correlation between measures of physical fitness and resistance to finger cooling.

A robust and "physically fit" person might show poorer or better resistance to cold stress depending on such factors as morale, exposure, isolation, fear, and task load. The interaction of numerous parameters in determining stress tolerance is an everpresent problem.

MORPHOLOGY

Davis (1961a) reported more than average shivering in two subjects who could be classified as ectomorphs. Fine and Gaydos (1959) found that heavy, big men felt warmer during cold stress than lightweight, small men. Small men, however, showed faster recovery rates than big heavy men. The authors indicated that small men suffer less cumulative effects of cold stress than big, heavy men. The paucity of information in this field leaves the question of selection of arctic personnel on the basis of body build open. As usual, a large number of other factors needs to be taken into consideration.

DIFFERENCES IN COMPLEXION

McCleary (1953) found a consistent, yet non-significant difference between "blonds" and "brunets" in manual performance under cold conditions. The blond group, which included red and brown-haired individuals as well, took less time to complete a manual dexterity task than did the brunets, who in this case were only black-haired individuals. This trend was not related to racial or national subgroups and was apparently unrelated to the "sensitivity index" discussed above. The results of this isolated report need further varification.

SEX DIFFERENCES

Women usually report greater discomfort due to cold and are said to prefer higher temperatures than men. This anecdotal observation has sometimes been interpreted as a sex difference in physiological thermoregulative mechanisms. An experiment by Yaglou and Messer (1941), reported by Tromp (1963, p. 231), however, has shown the differences in temperature sensation and comfort to be almost entirely due to differences in clothing worn.

PERSONALITY DIFFERENCES

Personality correlates of cold tolerance have been studied by a few investigators with generally negative results.

Fine and Gaydos (1959) obtained rectal temperatures, morphological measurements, MMPI scores, and ratings of subjective feeling from subjects exposed nude to 78°F (26°F), 70°F (21°C), and 50°F (10°C). Subjects whose scores on the derived anxiety index deviated widely from the group norm, took longer to show a rise in rectal temperature following exposure to cold. No differences in rectal temperature between the norm group and deviates were found prior to or during exposure.

Willemin, Kaplan, Katz, and deJung (1958) obtained scores on several psychological tests, biographical data, and peer ratings on 825 enlisted men in Cold Bay maneuvers at Fort Richardson, Alaska. The predictive validity of the instruments used was not at all impressive. The 1958 Combat Composites, Aptitude Areas, IN (Infantry) and AE (Combat Arms Other than Infantry) correlated .21 and .20 respectively, with peer ratings obtained on the basis of "desirability for inclusion with the rater on another cold weather maneuver." The Classification Inventory (CI), a composite measure of self-confidence, emotional stability, leadership, masculinity and social responsibility, correlated .22 with the criterion obtained from peer ratings of desirability. The Arctic BIB (Biographical Information Blank), a self-description blank to obtain the individual's self-estimate of his ability to cope with the tasks and hardships of arctic duty, the Shop Mechanics, and the Automotive Information Tests of the Army Classification Battery showed significant, but low correlations with the peer rating criterion. A low positive relationship between enlisted grade and desirability as "arctic duty companion" was also found. A multiple correlation was not reported. The question as to how representative companion desirability peer ratings are of actual performance under cold stress is highly debatable. In addition, the probability of contamination of the criterion by such factors as likability, friendliness, and the like should be deemed considerable.

Debons (1950) studied the interrelationship of MMPI scores and expressed levels of adjustment to arctic duty for a sample of infantrymen. The group that rated itself less able to adjust to the Alaskan tour had MMPI scores more like

the Army AWOL soldier, indicating greater depression, more neuroticism, and more schizoid tendencies than the rest of the sample. The group of individuals that expressed itself as adjusting favorably had MMPI scores that were less neurotic than the maladjusted group; they were also significantly higher on the psychopathic-deviate dimension than the norm group on which the MMPI scale was based.

On the basis of the research reviewed, it appears that adjustment to and tolerance of cold have not been found to be significant functions of stable personaltiy traits. Individuals who manifest considerable maladjustment, depression, loss of sleep, and other affective disturbances appear to do so for the same reasons in the Arctic as in more temperate climes. There is little evidence that this maladjustment should be attributed to predispositions reflecting particular personality or characterological sensitivities to low ambient temperatures. The combined rigors of thermal adjustment, isolation, confinement, and related factors at Arctic remote sites, with resulting frustration, boredom, interpersonal difficulties, and deprivations are sufficient to intensify and precipitate symptoms of maladjustment in some individuals, who might be screened prior to assignment if such screening were considered administratively indicated (Sells, 1962b).

SUMMARY

Although the question of selection of military personnel for arctic duty has in general been answered in the negative, the present review suggests that there is the possibility of exploiting individual differences in thermoregulation efficiency (Tromp, 1963, p. 252-255) and "sensitivity" (McCleary, 1953) that might afford a means of selection of personnel for particular tasks in which cold tolerance is critical and means of insulation and protection are not adequate, for example, the maintenance of power and communications lines and equipment in the open.

SECTION 8. SOCIAL FACTORS

Although we are not aware of any "hard" experimental data on the role of individual motivation and of group and social factors in relation to tolerance of cold stress, both anecdotal and field observations strongly support the following conclusions: (a) that the greater the motivation to achieve a particular goal, the greater the individual's tolerance of frustration and stress in activities leading to that goal (Sells, 1951; Bitterman and Holtzman, 1952; Lazarus, Deese, and Osler, 1952; Korchin, 1962); (b) that support contributing to the mitigation of stress is received in the participation in close-knit, well-trained groups through the effects of leadership, team spirit, and other aspects of the group process; and (c) that other social factors, involving intra- and intergroup relations, such as the effects of success and failure on communications, content of communications, and the like, have a significant effect on individual stress tolerance.

Karstens (1963) concluded that motivation is an important factor in the performance of aircraft maintenance crews working under adverse weather conditions. Motivated individuals were observed to make a special effort to combat the hardships imposed by the cold and to accomplish the task successfully. Reidy (1960) suggested that choosing volunteers for a hazardous and stress-laden arctic mission is an excellent selective device and a motivating force for a man to perform well.

The contributions of group processes to mitigation of the combined stresses of arctic duty have been discussed at some length by Sells (1961, 1962a, b, c). Some additional observations are included below from references omitted from or subsequent to Sells' reviews.

Reidy (1960) in his observations of several groups stationed on an isolated ice island in the Arctic at different times gave a vivid description of the deleterious effects of poor leadership on morale and the friction created by poorly

adjusted individuals in such small isolated groups. In the military situation, particularly, where the authority of the commander is of overriding importance in group behavior, such maladjustment may often be an effect of ineffective leadership behavior, with disrputive effects on group morale and consequently on group performance (Reidy, 1960; McCullum, 1950; Torrance, unpublished manuscript).

Bovard (1959) suggested that the presence of others, particularly those with whom the individual has previously interacted, may have "a protective effect under stress." Bovard hypothesized that the presence of a social stimulus will have a tempering effect on the individual's adverse physiological reaction to stress. Whether cold stress can be better withstood, and a high body temperature maintained in a group of persons with a previous history of interaction, than by an isolated individual, is open to empirical investigation. Unfortunately, social and physiological observations are not routinely collected simultaneously.

Separation of married men from their families, lack of sexual contact with the opposite sex, and absence of adequate recreational facilities are a few other problems that have been mentioned as adversely affecting morale and performance (McCullum, 1950; Torrance, unpublished manuscript).

The manner and thoroughness of preparatory indoctrination of personnel prior to exposure to stress is also an important aspect of stress-tolerance. Lack of competence and unrealistic anticipations resulting from inadequate or inaccurate information about expected conditions and conceivable emergencies (such as frostbite) can seriously handicap an individual or a group in environments fraught with difficulties and hazards. Proper concern for and care of injuries, alleviation of unfounded fears and anxieties, and instruction in survival procedures in the event of extreme emergencies are necessary aspects of the indoctrination and training required for personnel who are to be

exposed to extreme conditions. Prior experience in similar situations is invaluable, especially in the case of leaders, such as officers and non-commissioned officers. Understanding of behavioral reactions to be reasonably expected under extreme environmental conditions and their possible effects on group morale might provide commanders and subordinate leaders helpful "insight" into these problems when and if they occur. Such "insight," "understanding," or expectation might also reduce adverse and maladaptive reactions in trying and exacting social and environmental circumstances.

SECTION 9. CONCLUDING COMMENT

This review has described the psychophysiological effects of cold stress, the diverse parameters of cold stress that have an interactive effect in lowering the individual's tolerance to stress, and the means of counteracting the compounded effect of cold stress through acclimatization, training, selection, and indoctrination. Although the multidimensional and interactive aspects of so-called cold stress have often been reiterated, the requirements of exposition have made it necessary to treat both the effects and parameters of cold stress individually. In view of the complexity of the natural environment in which cold stress is most often encountered, it might have been more appropriate to entitle this paper, "The Psychophysiological Effects of Arctic and Polar Environments."

Despite the certainty that years of extensive experimentation and observation are yet needed to bring the scientific understanding of cold stress from its infancy to a more advanced level, comfort can be taken in the fact that investigations conducted to this date do not form a mixture of contradictions, as is so often the case in other fields of psychology and physiology. The evidence and conclusions on the effects of cold stress and the utility of counteracting measures are on the whole consistent. The investigations reported, conducted by scientists of different disciplines, are most often congruent and complementary. In spite of its insufficiency, a useful body of knowledge has started to develop in this field. Utilization of the principles and counteractive measures expounded in this paper can be expected to provide improved ability to cope with many practical situations in which cold stress and its correlates are operative.

REFERENCES

Adams, T. (Arctic Aeromedical Lab., Alaskan Air Command, Ladd AFB, Alaska.) The control of body temperature, TR No. 59-21, July, 1960.

Andersen, K. L., Stromme, S., and Elsner, R. W. (Arctic Aeromedical Lab., Aerospace Med. Div., Fort Wainwright, Alaska.) Metabolic and thermal responses to muscular exertion in the cold. (Proj. 8240-19). Rep. No. AAL-TDR-61-52, June, 1962.

Barnett, P. W. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Some effects of body heating prior to extreme cooling. Tech. Rep. No. 61-27, October, 1961.

Bartlett, D. J., and Gronow, D. G C (RAF Inst. Aviat. Med., England.) Manual dexterity and tactile sensitivity in the cold. FPRC Rep. 806, AD146 210, Nov., 1952.

Bitterman, M. E., and Holtzman, W. H. Conditioning and extinction of the galvanic skin response as a function of anxiety. J. abnorm. soc. Psychol., 1952, 47, 615-623.

Blair, E A., and Gottschalk, C. W. (Armored Med. Res. Lab.) Efficiency of signal corpos operators in extreme cold. Proj No 57-2, 1947.

Bollerud, J., Edwards, J., and Blakely, R. (Ladd AFB, Alaska.) A survey of the basal metabolism of Eskimos. Proj. No. 21-01-020, Dec., 1950.

Bovard, E. W. The effect of social stimuli on the response to stress. Psychol. Rev., 1959, 66, 267-277.

Braun, J. R., and Sells, S B. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Military small group performance under isolation and stress, critical review. III. Environmental stress and behavior ecology. Tech. Rep. No. AAL-TDR-62-33, June, 1962

Bruce, W. Man and his thermal environment. Ottawa, Can., NRCC Tech. Rep. 84, AD 236 020, Feb., 1960.

Buchanan, A. R., and Hill, R. M. Temperature regulation in albino rats correlated with the determination of myelin density in the hypothalamus. Proc. Soc. Exper. Biol. and Med., 1947, 66, 602-608.

Burns, Major G. C. Neuropsychiatric problems at an Aleutian post. Amer. J. Psychiat., 1945, 102, 205-213.

Burton, A. C., Synder, R. A., and Leach, W. G. Damp cold versus dry cold. Specific effects of humidity in heat exchange of unclothed men. J. appl. Phsiol., 1955, 8, 269-278.

Buskirk, E. R., Thompson, R. H., Moore, R. and Whedon, G. P. Human energy expenditure studies in the National Inst. of Arthritis and Metabolic Diseases Metabolic Chamber. I. Interaction of cold environment and specific dynamic effect. II. Sleep. Amer. J. Clin. Nutrition, 1960, 8, 602-613.

Carlson, L. D., and Thrush, H. L. (Alaskan Air Command, Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Cold injury and frost bite: a selected, annoted bibliography. Dec., 1960.

Clark, R E. (Quartermaster Res. and Eng. Command, Natick, Mass.) The limiting hand-skin temperature for unaffected manual performance in the cold. Tech. Rep. EP-147, Feb., 1961.

Clark, R. E., and Cohen, A. I. Manual performance as a function of rate of change in hand-skin temperature. J. appl. Physiol., 1960, 15, 496.

Clark, R E., and Jones, C. E. Manual performance during cold exposure as a function of practice level and the thermal conditions of training. J. appl. Psychol., 46, 276-280.

Coffey, M. F. An examination of joint stiffness in the cold as measured by Hunter's Flexion Test on acclimatized troops of Indian and Eskimo origin from the Northwest

Territories. Canadian Defense Res. Board, DRML Tech. Paper No. 15, 1955.

Cohen, A. I. (Alaskan Air Command. Arctic Aeromedical Lab., Ladd, AFB.) The effect of cold exposure on hepatic acetate metabolism. TR 57-4, July, 1960.

Craik, K. J. W., and Macpherson, S. J. Effects of cold upon hand movement and reaction time. CAV, Eng. MPRC-BPC Rep. 43/196, 1943.

Davis, R. C. Modification of the galvanic reflex by daily repetition of a stimulus. J. exp. Psychol., 1934, 17, 504-535.

Davis, T. R. A. Chamber acclimatization in man. Report on studies of physiological effects of cold on man. Army Med. Res. Lab., Rep. No. 475, 1961a.

Davis, T. R. A. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) The effect of acclimatization on responses to cold stress. Tri-Service Conference on Research Relevant to Behavior Problems of Small Military Groups under Isolation and Stress. AF Contract 41 (657)-323, 1961b.

Davis, T. R. A. The effect of heat acclimatization on artificial and natural cold acclimatization in man. Report on studies on physiological effects of cold on man. Army Med. Res. Lab. 1961c.

Davis, T. R. A., and Joy, R. J. T. (Army Res. Off., Office of the Chief, Res. and Devel., Washington, D. C.) Cold injury and cold acclimatization in man. 1962.

Debons, A. Personality predisposition of infantry men as related to their motivation to endure tour in Alaska; a comparative evaluation survey of human adjustment problems in the northern latitudes. Part III, Program E, Ladd AFB, Alaska, Proj. No. 21-01-022, May, 1950.

Debons A., and Chiles, W. D. The effects of cold on psychophysical weight judgments; a methodological study. Wright-Patterson AFB, Ohio, WADC Tech. Rep. 57-305, AD 131 004, 1957.

Denley, H. L (Alaskan Air Command, Arctic Aeromedical Lab., Ladd AFB, Alaska.) Cold weather tests on pneumatic shelter raft. Tech. Note AAL-TN-57-18, July 1957.

Douglas, J. D. (Alaskan Air Command, Arctic Aeromedical Lab., Ladd AFB, Alaska.) The evaluation of the use of ultrasound in frostbite therapy. Tech. Note AAL-TN-60-11, August, 1960.

Drury, H. F. (Arctic Aeromedical Lab., Aerospace Med. Div., AF Systems Command, Ft. Wainwright, Alaska.) Direct observations of the mode of invasion of living tissue by ice. Tech. Doc. Rep. AAL_TDR-63-27, Aug., 1964.

Dusek, E. R. Manual performance and finger temperature as a function of ambient temperature. QRDC Tech. Rep. EP-68, AD 148 222, Oct., 1957.

Eagan, C. J. Factors affecting tolerance to cooling of the fingers. Physiologist, 1962, 5, 133. (Abstract)

Edwards, J. Electroencephalographic study of men transferred from the subtropic to the subarctic. Ladd AFB, Alaska, Proj. No. 21-01-004, Sec. IV, Dec., 1960.

Fine, B. J., and Gaydos, H. F. Relationship between individual personality variables and body temperature response patterns in the cold. Psychol. Rep., 1959, 5, 71-78.

Forlano, G. The effect of ambient and body temperatures upon reaction time. Tech. Data Digest, 1950, 15, 18-26.

Fuhrman, F. A., and Fuhrman, G. J. The treatment of experimental forstbite by rapid thawing: a review and experimental data. Medicine, 1957, 36, 465-487.

Funtikow, B. A. Adequatometric investigation of the visual and auditory analysis of man in the process of adaptation to climatic conditions. In Soviet research on factors affecting man's visual and auditory analyzers. Joint Publ. Res. Serv., Washington, D. C., Jan. 14, 1964. (Abstract)

Gaydos, H. F. Effect of complex manual performance of cooling the body while maintaining the hands at normal temperatures. J. appl. Physiol., 1958, 12, 373-376.

Gaydos, H. F., and Dusek, E. R Effects of localized hand cooling versus total body cooling on manual performance. J appl. Physiol., 1958, 12, 377-380.

Glaser, E. M., and Whittow, G. C. Retention in a warm environment of adaptation to localized cooling. J. Physiol., 1957, 136, 98-111.

Heberling, E J., and Adams, T. Relation of changing levels of physical fitness of human cold acclimatization. J. appl. Physiol., 1961, 16, 226-230.

Horvath, S. M., and Freedman, A. The influence of cold upon the efficiency of man. J. Aviat. Med., 1947, 18, 158-164.

Iampietro, P. F., Vaughan, J. A , et al. (Quartermaster Res. and Eng. Command, Natick, Mass.) Heat production from shivering. Tech. Rep. No. EP-145, Jan., 1961.

Karstens, A. J. (Arctic Aeromedical Lab., Air Force Systems Command, Ft. Wainwright, Alaska.) Effect of weather factors on aircraft maintenance crews in the arctic areas. AAL-TDR-63-18, June, 1963.

Korchin, S. Some psychological determinants of stress behavior. (unpublished manuscript), 1962.

Kreider, M. B Effect of diet on body temperature during sleep in the cold. J. appl. Physiol., 1961, 16, 239-242.

Lazarus, R. S., Deese, J., and Osler, S. F The effects of psychological stress upon performance. Psychol. Bull., 1952, 49, 293-317.

LeBlanc, J. S. Impairment of manual dexterity in the cold. J. appl. Physiol., 1956, 9, 62-64.

Lewis, R. B. Local cold injury. A critical review. Amer. J. Phys. Med., 1955, 34, 538-678.

Lewis, R. B., and Hoak, G G. Effect of delayed warming on experimental frostbite. U. S. Armed Forces Med. J., 1956, 7, 172-178.

MacCanon, D. M. (South Dakota Univ. School of Med. Sci) Effect of oxygen infalation on manual performance in the cold. Contract DA 49-007-md-1008, April 30, 1961.

MacCanon, D. M. (Chicago Univ. Med. Sch., Chicago, Ill.) Effect of oxygen inhalation on responses to cold exposures. Annual Progress Report, Grant No. DA-Md-49-193-62-643, Sept. 30, 1962.

McCleary, R. A (Air Univ., USAF Sch. of Aviat. Med., Randolph Field, Tex.) Psychophysiological effects of cold. I. The role of skin-temperature and sensory sensitivity in manual performance decrement. Jan., 1953.

McCullum, E. L Morale survey of personnel assigned to Elmendorf AFB, Alaska. Survey of human adjustment problems in the northern latitudes. Proj. No. 21-01-002. Part 1-B, Program C, Ladd AFB, Alaska, May, 1953.

Macfarlane, W. V. General physiological mechanisms of acclimatization. In S. W. Tromp (Ed.), Medical Biometeorology. New York: Elsevier Publ. Co., 1963, pp. 372-417.

Mackworth, N. H. (Med. Res. Council, Applied Psychology Res. Unit, Cambridge, Eng.) Finger numbness in very cold winds. APU 151/51, Nov., 1951.

Mackworth, N. H. Some recent studies of human stress from a marine and naval viewpoint. Trans. Inst. Mar. Engrs., 1952, 64, 123-132.

Martorano, J. J. Evaluation of divers' dress suits in maintaining body temperature in cold water. Naval Med. Field Res. Lab., Oct., 1961.

Masoro, E. J. (Arctic Aeromedical Lab., Ladd, AFB, Alaska.) Alterations in hepatic lipid metabolism induced by acclimation to low environmental temperatures. TR 59-25. July, 1960.

Mayer, J. (Alaskan Air Command, Arctic Aeromedical Lab., Ladd AFB, Alaska.) Cold weather test of insulated underwear. AAL-TN-60-21, Nov., 1960.

Meryman, H. T. (Naval Med. Res. Inst., Bethesda, Md.) The mechanism of local cold injury. Proj. NM-000-018.01.07, 1953, 11, 741-766.

Milan, F. A. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska,) Thermal stress in the Antarctic. AAL-TR-60-10, Mar., 1961.

Milan, F. A., and Rodahl, K (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Nutrition and energy expenditure at Little America in the Antarctic. AAL-TR-60-11, Mar., 1961.

Milan, F. A., Elsner, R W., and Rodahl, K. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) The effect of a year in the Antarctic on human thermal and metabolic responses to an acute standardized cold stress. Tech. Rep. 60-9, Mar., 1961.

Miller, K. L., and Irving, L. Local reactions to air cooling in an Eskimo population. J. appl. Physiol., 1962, 17, 449-455.

Mills, A. W. Finger numbness and skin temperature. J. appl. Physiol., 1956, 9, 447-450. AD 144 497.

Moos, W. S. The effects of "Fohn" weather on accident rates in the city of Zurich (Switzerland). Aerospace Med., 1964, 35, 643-645.

Muecher, H., and Ungeheuer, H. Meteorological influence on reaction time, flicker fusion frequency, job accidents, and use of medical treatment. Percept, Motor Skills, 1961, 12, 163-168.

Nelms, J. D., and Soper, D. J. G. Cold vasodilation and cold acclimatization in the hands of British fish filleters. J. appl. Physiol., 1962, 17, 444-448.

Newton, J. M. An investigation of tracking performance in the cold with two types of control. Ft. Knox, Ky., AMRL Rep. 324, AD 160 342, Sept., 1957.

Payne, R. B. Tracking proficiency as a function of thermal balance. J. appl. Physiol., 1959, 14, 387-389.

Peacock, L. J. A field study of rifle aiming steadiness and serial reaction performance as affected by thermal stress and activity. Ft. Knox, Ky., AMRL Rep. 231, AD 92 230, April, 1956.

Pribram, K. H. A review of theory in physiological psychology. In P. R. Farnsworth and Q. McNemar (Eds.), Annual review of psychology, Vol. 11. Palo Alto, California: Annual Reviews, Inc., 1960.

Provins, K. A Environmental conditions and driving efficiency: a review. Ergonomics, 1958, 2, 97-107.

Provins, K. A., and Clarke, R. S J. The effect of cold on manual performance. J. Occup. Med., 1960, 2, 169-176.

Provins, K. A., and Morton, R. Tactile discrimination and skin temperature. J. appl. Physiol., 1960, 15, 155-160.

Reidy, J. J. (Alaskan Air Command, Arctic Aeromedical Lab., Ladd AFB, Alaska.) Fletcher's ice island: a psychiatric report. Tech Rep. 59-9, Jan., 1960.

Renbourn, E. T. Influence on different types of clothing. In S. W. Tromp (Ed.). Medical Biometeorology. New York: Elsevier Publ. Co., 1963, pp. 426-435.

Revesman, S. L., Hollis, J. R., and Mattson, J. B. A literary survey of human performance under Arctic environment. DA, Washington, D. C., RDD Tech. Memo. 6, AD 63 045, Dec., 1953.

Rodahl, K., Horvath, S. M., et al. Effects of dietary protein on performance capacity of man and dog in cold environment. Lankenau Hosp. Res. Inst., Rep. No. 1, Jan. 31, 1961.

Rogers, T. A., Setliff, J. A., and Klopping, J. C. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) The caloric cost and fluid and electrolyte balance in simulated subarctic survival situations. AAL-TDR-63-16, Dec., 1964.

Rohles, F. H., Jr. Two studies on temperature and motor ability: the effects of temperature on serial discriminative responses: the effect of time and temperature on motor ability. Ladd AFB, Alaska, AAL Project 22-0601-0002, Rep. 1, AD 52 056, Nov., 1953.

Russell, R W. Effect of variations in ambient temperatures on certain measures of tracking skill and sensory sensitivity. Ft. Knox, Ky., AMRL Rep. 300, AD 146 210, Nov., 1957.

Sells, S. B. (Air Univer., Sch. of Aviat. Med., Randolph Field, Texas.) A research program on the psychiatric selection of flying personnel. 1. Methodological introduction and experimental design. Nov., 1951.

Sells, S. B. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Military small group performance under isolation and stress - an annotated bibliography. VI. Leadership in formal groups. Tech. Rep. No. 61-24, Oct., 1961.

Sells, S. B. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Military small group performance under isolation and stress - critical review. I. Informal, natural groups: development, structure, and function. Tech. Rep. No. AAL-TDR-62-31, June, 1962a.

Sells, S. B (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Military small group performance under isolation and stress - critical review. IV. Selection, indoctrination, and training for arctic remote duty. Tech. Rep. No. AAL-TDR-62-34, June, 1962b.

Sells, S. B. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Military small group performance under isolation and stress - critical review. V. Psychological principles of management and leadership. Tech. Rep. No. AAL-TDR-62-34, June 1962c.

Sills, F. D., and O'Riley, V. E. Comparative effects of rest, exercise, and cold spray upon performance in spot-running. Res. Quart. Amer. Assoc. Health phys. Educ., 1956, 27, 217-219.

Skrettingland, K. R. (Alaskan Air Command, Ft. Wainwright, Alaska.) Arctic field evaluation of vapor impermeable gloves. Flying Tech. Note AAL-TN-60-30, Feb., 1961.

Skrettingland, K. R., Clogston, J., and Veghte, J. H. (Alaskan Air Command, Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Evaluation of various types of boots in cold environments. Tech. Note AAL-TN-61-7, Oct., 1961.

Springbett, B. M. The effects of exposure to cold on motor performance. DRNL, Can., AD 6753, 1951.

Teichner, W. H. Manual dexterity in the cold. J. appl. Physiol., 1957, 11, 333-338.

Teichner, W. H. Reaction time in the cold. J. appl. Psychol., 1958, 42, 54-59.

Teichner, W. H., and Kobrick, T. L. Effects of prolonged exposure to low temperature on visual motor performance, flicker fusion, and pain sensitivity. J. appl. Psychol., 1955, 49, 122-126.

Teichner, W. H., and Wehrkamp, R. F. Visual motor performance as a function of short-duration ambient temperature. J. exp. Psychol., 1954, 47, 447-450.

Theis, F. V., O'Conner, W. R., and Wahl, F. J. Anticoagulants in acute frostbite. J. Amer. Med. Assoc., 1951, 146, 992-995.

Torrance, E. P. Surviving emergencies and extreme conditions. A summary of six years of research. (Unpublished manuscript.)

Tromp, S. W. (Ed.) Medical biometeorology. New York: Elsevier, 1963.

Trumbull, R. Personal communication, 1964.

Veghte, J. H. (Arctic Aeromedical Lab., Ft. Wainwright, Alaska.) Human physiological response to extremity and body cooling. Proj. No. 8242-2, AAL-TR-61-26, Oct., 1961.

Veghte, J. H. (Biomed. Lab., Aerospace Med. Res. Lab., Aerospace Med. Div., AF Systems Command, USAF, Wright-Patterson AFB, Ohio.) Respiratory and microclimate temperatures within the parka hood in extreme cold. AMRL-TDR-64-79, Sept., 1964.

Weitz, J. Vibratory sensitivity as a function of skin temperature. J. appl. Psychol., 1941, 28, 21-36.

Williams, C. C., and Kitching, J. A. The effects of cold on human performance. NRCC, Ottawa, Canada, March, 1942.

Willemin, L. P., Kaplan, H., Katz, A., and deJung, J. E. Prediction of enlisted performance under conditions of extreme cold. USA Tago Personnel Res. Br., Tech. Res. Rep. No. 113, 1958.

Yaglou, C. P., and Messer, A. The importance of clothing in air conditioning. J. Amer. Med. Assoc., 1941, 117, 1261-1267.

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13. ABSTRACT

This report reviews several topics in the area of cold stress, including the process of thermoregulation, human performance under cold stress, physiological injury, deteriotation of morale, acclimatization, individual differences, and tolerance of cold. Ways and means of counteracting cold stress to improve task performance are emphasized.

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Body temperature						
Cold						
Cold exposure						
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